THE DESIGN AND INSTALLATION OF A DISSIPATION ARRAY SYSTEM FOR LIGHTNING PREVENTION

BY

Engr. U. T. Itaketo
Engineering Department, Mobil Oil Corporation,
Qua Iboe Terminal, P.M.B. 12054, Lagos, Nigeria

Abstract:

In this paper, a device known as the Dissipation Array System (DAS), acclaimed to prevent lightning strikes within its immediate vicinity, is presented. The design and installation specifications of the system are presented. Though the system functions effectively, the principles behind its operation is not well-developed. However, the electrostatic field theory behind the operation of the DAS is developed in mathematical equations and presented in this paper.

Keywords: lightning strikes; point discharge principle; electric field strength; the dissipation array system (DAS).

1 Introduction

Lightning, defined as electrical discharges that take place in the atmosphere between oppositely-charged clouds or between clouds and the ground [1], is a natural phenomenon that is inherently dangerous. When it occurs, it releases voltages that are in the kilovolts ranges and currents in kiloamperes ranges as well. Also, electrical energy released are in megajoules. Highly- valued properties, natural and artificial have been known to be lost to its effects. In some cases, it even kills. Its occurrence is therefore detrimental and deserves to be controlled.

A device known as the Dissipation Array System (DAS), made of thin steel conductors and arranged in arrays over a facility to be protected, has been invented and is acclaimed to prevent lightning from striking within its area of installation but the theory behind its operation is not well-developed [2]. Theoretical explanations, based on known scientific laws, to the "WHY" and "HOW" of this system's unique capability to prevent lightning strikes are offered.

Since its invention back in 1990, the DAS has been installed in several locations around the world. Some of the locations where it has been installed and proved effective are Shell Oil Terminal at Escravos, Mobil's Oil Terminal, Qua Iboe, (both in Nigeria), Union Camp Plant, Exxon LNG Plant, PPG Chemical Plant and Texaco Plants all in United States of America, (USA)[2].

2 The design of the DAS

The DAS comprises three (3) basic elements as follows:

(a) The Ionizers (dissipators)
(b) The Earth Copper Tapes
(c) The Ground Current Collectors (GCCs)

Straight stainless steel wires of about $2mm^2$ by cross-sectional area are used to form the dissipators. At about 10cm spacing along the length of the wire, parts of the wire (V-shaped and about 10cm long), are braced to the straight wires. The steel wires are braced to earth copper tapes at about 10 meter intervals for electrical continuity.

The earth copper tapes function to provide direct and low-resistance paths for ionization current from the GCCs to the ionizers. These tapes carry low current levels over the least possible resistance paths and the current flow is in the milliamperes range.

The GCCs are copper rods of about 70mm^2 in cross-sectional area. They provide the path for ground current movement from the earth to the ionizers. The rods are about 1.5m long and have about 99% of its total length buried vertically into the earth. Interval spacing of about 10 meters is maintained between every two GCC in each installation. This is to obtain effective low resistance path to the ground. The GCCs are inter-connected by a net of copper conductors of 4mm^2 by cross-sectional area.

3 Installation of the DAS

The dissipators are installed at about 1.5m from the top of the protected facility, supported by metallic arm brackets. The copper tapes are run on the surface of the protected facility while the GCCs are buried into the earth as previously described. The DAS is a passive system; consumes no power and is activated by the energy of the storm itself. The entire arrangement, as described, is illustrated in fig. 1.

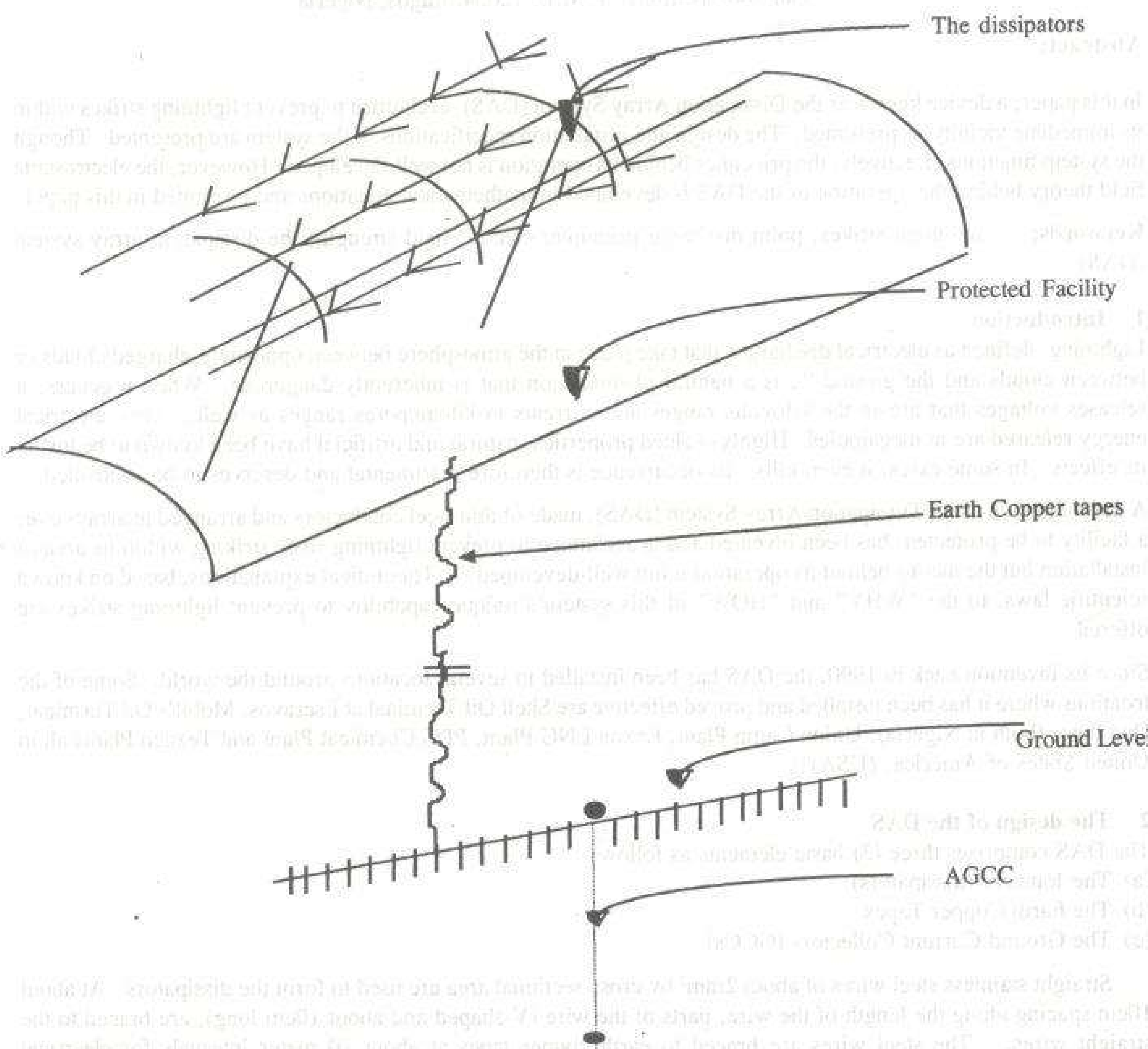

Fig. 1: Sectional Arrangement of DAS Installation

4 The Development of Theoretical Principles of Operation of the DAS

In contrast to the traditional single-pointed lightning rod/earth mass arrangement, which mostly tends to attract lightning-bound charges to itself, the DAS is a multi-point device designed to efficiently produce negative ions from many points simultaneously. Since these ions are spread over a large area, no breakdown of charges can occur. It functions as follows: As the ground currents flow into the protected area, they first interface with the GCCs which provide preferred paths for the charges from the point of interface to the dissipator assembly through the earth copper tapes. These current are, through the process described above, drained as negative charges into the air space above the dissipators.

The flow of charges from the dissipators through the air space above it reduces the potential of the protected site and the facility with respect to its surroundings by draining the charges from the protected area. The presence of free ions or space charges between the protected facility and the cloud structure forms a type of Faraday shield between them thus providing some form of isolation for the facility from much of the storm influence. It is believed that the entire process described above is made possible through one principle: The point discharge principle. This belief has to be substantiated and proved. The following presentation supports that belief.

5 Operation of the DAS from the point discharge principle

The point discharge principle is a phenomenon that has been known to scientists for centuries. It is based on the following facts: "A sharp metallic point immersed in a strong electrostatic field, where its potential could be raised to about 10,000 volts or above, with respect to its surroundings, would leak off electrons by ionizing the adjacent air molecules" [3]. From that statement, it can be seen that the point takes an electron from an adjacent air molecule, leaving it a free ion. The electrostatic field draws away the ion from the point and the process continues as long as the storm is in the area and high-enough potential is present. When large amount of ions are produced in this way, it creates a related phenomenon called corona discharge. The DAS thus creates massive ionization during a mature storm, thereby constantly discharging the protected area and prevents the condition that would have otherwise caused lightning strike.

The point discharge principle just described above is largely based on the principle of continuity of charges which is expounded below.

6 The Principle of Continuity of Charges

From electrostatics, where changes of volume charge density occur, the field of conduction current density vector $\overline{J}$ is a source field in the regions [4].

A very strong magnetic field intensity vector $\overline{H}$ is always associated with these regions. The electromagnetic expression relating $\overline{H}$ to $\overline{J}$ is as follows:

$$Curl\ \overline{H} = 4\pi\overline{J} + \frac{\partial\overline{D}}{\partial t} \quad \text{(1), Ref.[5].}$$

(Maxwell's 2nd equation)

where $\overline{H}$ and $\overline{J}$ are as previously defined and 4π a constant.

$\frac{\partial\overline{D}}{\partial t}$ is termed the displacement current.

Equation (1) can be re-expressed as

$$i\frac{\partial Hx}{\partial x} + j\frac{\partial Hy}{\partial y} + k\frac{\partial Hz}{\partial z} = 4\pi J + \frac{\partial D}{\partial t} \quad \text{(2)}$$

the vector quantity H being expressed in rectangular co-ordinates.

Alternatively, it can be expressed as:

$$\nabla \times \overline{H} = 4\pi \overline{J} + \frac{\partial \overline{D}}{\partial} \quad \text{.......................................(3)}$$

where the symbol ∇ is known as "nabla", its definition being $i\frac{\partial}{\partial x} + j\frac{\partial}{\partial y} + k\frac{\partial}{\partial z}$

Taking divergence (div) on both sides of equation (1).

$$div.\,curl\,\overline{H} = \left(div.\ 4\pi \overline{J}\right) + \frac{\partial D}{\partial t}$$

$$\nabla.\ \nabla x\,\overline{H} = \nabla.\left(4\pi \overline{J}\right) + \frac{\partial D}{\partial t}$$

but $\nabla.\ (\nabla x\,\overline{H}) = 0$ ie $div.\ Curl\,(\overline{H}) = 0$ [5]

$$\therefore \left(\nabla\ 4\pi \overline{J} + \frac{\partial \overline{D}}{\partial t}\right) = 0$$

$$4\pi \nabla.\overline{J} + \frac{\partial \nabla.\overline{D}}{\partial t} = 0$$

$$4\pi \nabla.\overline{J} = -\frac{\partial \nabla.\overline{D}}{\partial t} \quad \text{.......................................(4)}$$

Recalling the following relations from electrostatics,

$$\overline{J} = \sigma \overline{E}$$

$$\nabla.\overline{D} = \rho_v$$

$$\overline{E} = \frac{\overline{D}}{\varepsilon_0 \varepsilon_r} \quad \text{Ref [5].}$$

where:

σ is conductivity

$\overline{E}$ is electric field intensity

$\overline{D}$ is current density

ρ_v is volume free charge density

ε_0 is permittivity of free space

ε_r is relative permittivity

Hence, equation (4) becomes :

$$4\pi \nabla \left(\sigma \overline{E} \right) = \frac{-\partial \rho_v}{\partial t}$$

$$4\pi \nabla \frac{\sigma \overline{D}}{\varepsilon_o \varepsilon_r} = \frac{-\partial \rho_v}{\partial t}$$

$$\frac{\sigma 4\pi \nabla . \overline{D}}{\varepsilon_o \varepsilon_r} = \frac{-\partial \rho_v}{\partial t}$$

$$\frac{\sigma 4\pi \rho_v}{\varepsilon_o \varepsilon_r} = \frac{-\partial \rho_v}{\partial t}$$

separating variables.

$$\frac{4\pi\sigma}{\varepsilon_o \varepsilon_r} \partial t = \frac{-\partial \rho_v}{\rho_v} \qquad \text{...(5)}$$

By integrating both sides of equation (5).

$$\frac{4\pi\sigma}{\varepsilon_o \varepsilon_r} \int \partial t = - \int \frac{\partial \rho_v}{\rho_v}$$

$$\frac{4\pi\sigma t}{\varepsilon_o \varepsilon_r} = -\log_e \rho_v$$

$$\rho_v = \rho_o e^{-\left(\frac{4\pi\sigma t}{\varepsilon_o \varepsilon_r}\right)} = \rho_o e^{-\left(\frac{t}{\frac{\varepsilon_o \varepsilon_r}{4\pi\sigma}}\right)} = \rho_o e^{-\left(\frac{t}{\theta}\right)}$$

$$\therefore \rho_v = \rho_o e^{-\left(\frac{t}{\theta}\right)} \qquad \text{...(6)}$$

where $\theta = \frac{\varepsilon_o \varepsilon_r}{4\pi\sigma}$ and known as electrostatic time constant and

ρ_o is initial charge density.

Equation 6 is known as the continuity equation. Stated in words, it expresses the fact that the net flow of charges from any volume region is a measure of the time rate of decrease of free electrical charges inside the volume. That statement summarizes the earlier explanation on the movement of charges from the DAS to any charged vicinity.

To further explore the scientific principle behind the operation of the DAS, the following electrostatic equations are recalled:

$$E = -\nabla V \qquad (7)$$ [5]

where E = Electric field strength radiated by the DAS

V = The electric potential from the DAS and

∇V = The gradient of V from the DAS

In equation (7), E has a negative sign because it decreases as the distance from its source increases. Also, it is recalled that $\nabla^2 V = \frac{-\rho}{\varepsilon}$ ....(8) [5]

where ∇^2 = nabla operator

ρ = charge per unit volume

$\varepsilon = \varepsilon_0 \varepsilon_r$ = permittivity of space

Equation (8) is known as Poisson's equation. For completeness, solutions for E and V will be considered in spherical co-ordinates, in the directions of r, θ and ϕ.

Solutions for E are as follows:

$$E_r = -j\omega E_r - \frac{\partial v}{\partial r} \qquad (9)$$

$$E_\theta = -j\omega E_\theta - \frac{1}{r}\frac{\partial v}{\partial \theta} \qquad (10)$$

$$E_\phi = -j\omega E_\phi - \frac{1}{r \sin\theta} \cdot \frac{\partial v}{\partial \phi} \qquad (11)$$ [5]

and the integral form solution for the Poisson's equation is given by

$$V = \frac{\mu_0}{4\pi E}\int_{V^1} \frac{\rho \, dv^1}{r} \qquad (12)$$ [5].

all parameters as previously defined and V^1 is the considered volume.

Both E and V provide the DAS its unique capability of neutralizing any lightning-bound charges within its vicinity. Expressions for E and V in this respect will now be derived.

7 Determination of Electric Field Strength E and Potential V Due to charges Radiative Effects of DAS

Let the general expression for the current density on each of the dissipating wires be

$$i = i_0 \cos \omega t \qquad (13)$$

An electric field strength E (a vector quantity), created due to the radiative effect of the DAS is obtained by the following expression:

$$E = \frac{\mu_o}{4\pi}\int \frac{i_o \cos \omega t}{r}\, dv \qquad \text{.....(14)[4]}$$

In equation (14), r is the distance of the volume element of current dv to a point, say P, where the field strength E is to be determined. Now, electrostatic or electromagnetic disturbances propagate with finite velocity C m/s. However, during the charge dissipation process, where there is a transition of charges from the wires to the vicinity, there is a delay in time t due to electrostatic impedance in the vicinity of the DAS wires. This time delay is expressed mathematically as:

$$t_d = \frac{r}{c} \text{ seconds} \qquad \text{.....(15)}$$

The field strength E now becomes

$$E = \frac{\mu_o}{4\pi}\int \frac{i_o \cos \omega (t - t_d)}{r}\, dv \qquad \text{.....(16)}$$

or

$$E = \frac{\mu_o}{4\pi}\int \frac{i_o \cos\left(t - \frac{r}{c}\right) dv}{r} \qquad \text{.....(17)}$$

By a similar analogy, recalling equation (12), the potential difference (a scalar quantity), around the DAS, created due to the time-varying charges is given by:

$$V = \frac{1}{4\pi\iota}\int \frac{\rho_o \cos \omega\left(t - \frac{r}{c}\right)}{r}\, dv \qquad \text{.....(18)}$$

Equations (17) and (18) both show that the changes in E and V at the field point are associated with changes in current and charges respectively at an earlier time t_1, where

$$t_1 = t - \frac{r}{c} \text{ seconds} \qquad \text{.....(19)}$$

These potentials, retarded in time, would be expected, and are synonymously referred to as retarded potentials. Hence, for any general function of current and charge [$i = i(t)$ and $\rho = \rho(t)$], expressions for the retarded potentials for E and V have the general form:

$$E = \frac{\mu_o}{4\pi}\int \frac{i\left(\frac{t - t}{c}\right)}{r}\, dv \qquad \text{.....(20)}$$

$$V = \frac{1}{4\pi\varepsilon}\int \frac{\rho\left(\frac{t - r}{c}\right)}{r}\, dv \qquad \text{.....(21)}$$

$$\text{where } \rho = \rho_0 \cos\omega\left(t - \frac{r}{c}\right)$$

Next, the vector quantity (electric field strength E), and the scalar quantity (potential difference V) will be given through vectorial and scalar analyses respectively in spherical co-ordinates. By that procedure, it will be possible to determine the extent of their influences around the DAS hence indirectly determining the extent of coverage of the DAS.

8 Determination of Extent of Coverage of the DAS Installation

The electric field strength E which results from the dissipative action of the array system is studied more closely by analyzing E in each dissipator in spherical co-ordinates as illustrated in fig. 2 below.

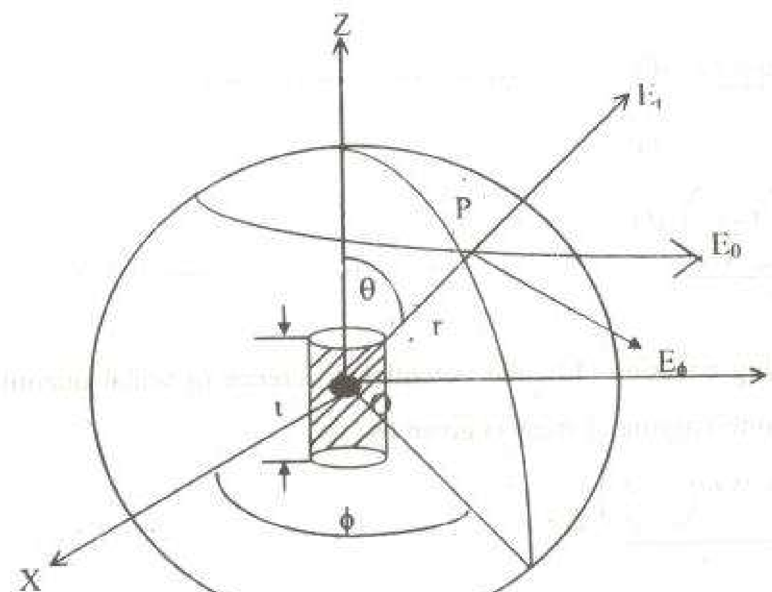

Fig. 2: Presentation of Electric Field Strength E due to the DAS, in spherical co-ordinates

In the figure above, E_r, E_ϕ and E_θ represent electric field strengths (vector quantities), due to the dissipative action of DAS (one unit indicated by length ι) in the directions of r, angle φ and angle θ. The entire system is represented in spherical co-ordinates. The retarded vector potential, E_z at any point within the sphere, say P, has the expression

$$E_z = \frac{\mu_0}{4\pi}\int_{-\iota/2}^{\iota/2} \frac{I_o e^{j\omega(t-r/c)}}{r}\, dz \text{ ....(22)}$$

Equation (22) is basically equation (16) where the current $I_o \cos\omega(t-r/c)$ has been replaced by its exponential notation. The retarded vector potential (Electric field strength E) at a distant field point P is studied more closely by taking reference from the polar axis (Z-axis) as illustrated in fig. 3.

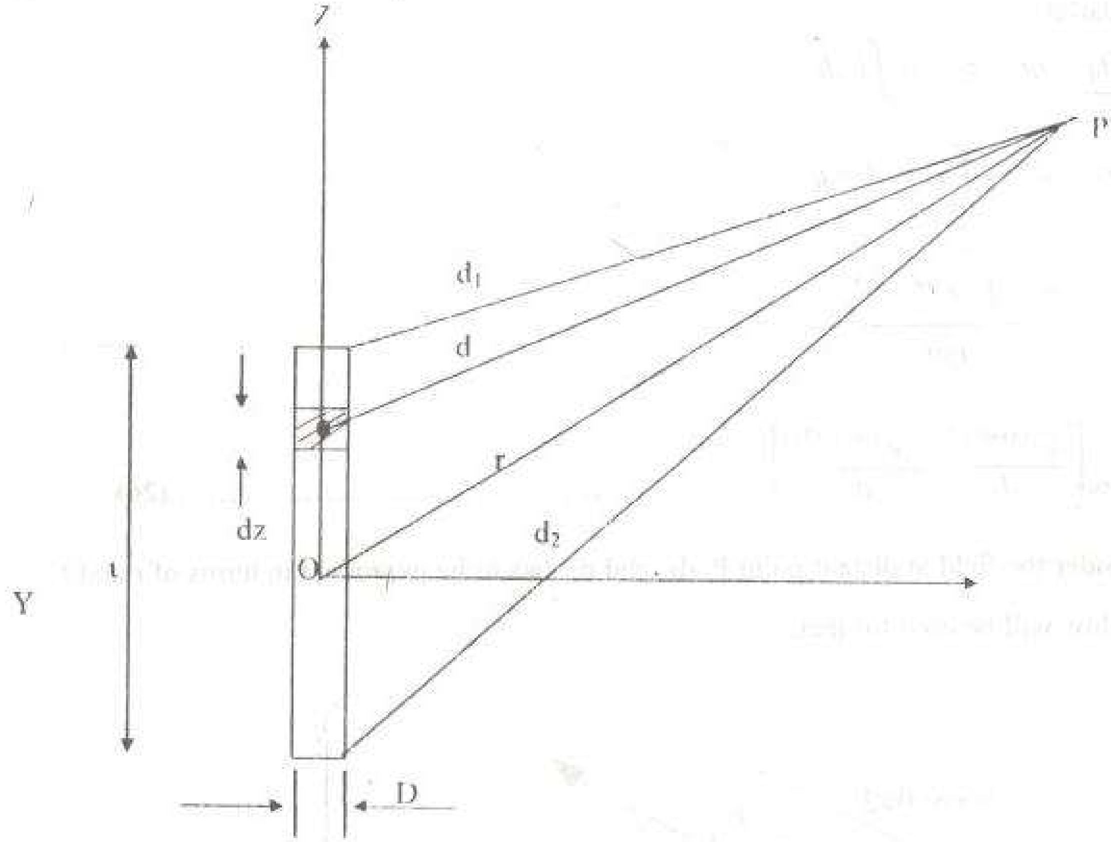

Fig. 3: Elemental Analysis of E from the Polar axis Z

From fig. 3 above, and recalling equation (22).

$$\left(E_z = \frac{\mu_o}{4\pi}\int_{-t/2}^{t/2} \frac{I_o e^{j\omega(t-r/c)}}{r}\, dz \right).$$

since P is considered to be at a distant point P, far away from O, the origin, this implies that $r >> t$. Also, let $r \cong d$. From these considerations,

$$E_z = \frac{\mu_o\, t\, I\, e^{j\omega(t-r/c)}}{4\pi r} \qquad \text{......(23)}$$

Similarly, the retarded scalar potential V of charge distribution on the pole is

$$V = \frac{1}{4\pi\varepsilon_o}\int \frac{\rho_o\, e^{j\omega(t-d/c)}}{d}\, dv \qquad \text{......(24)}$$

But from point discharge theory, charges are assumed to be mostly at the ends, hence

$$V = \frac{1}{4\pi\varepsilon_o}\left[\frac{q\, e^{j\omega(t-d1/c)}}{d_1} - \frac{q\, e^{j\omega(t-d2/c)}}{d_2}\right] \qquad \text{......(25)}$$

Recalling the equation

$$I = \frac{dq}{dt} \quad or \quad q = \int I \, dt$$

$$q\, e^{j\omega(t-d\,c)} = I_o \int e^{j\omega(t-d\,c)} \, dt$$

$$q\, e^{j\omega(t-d\,c)} = \frac{I_o \, e^{j\omega(t-d\,c)}}{j\,\omega}$$

$$\therefore \; V = \frac{I_o}{4\pi\varepsilon_o j\omega}\left[\frac{e^{j\omega(t-d1\,c)}}{d_1} - \frac{e^{j\omega(t-d2\,c)}}{d_2}\right] \quad \text{..........(26)}$$

However, to consider the field at distant point P, d_1 and d_2 has to be expressed in terms of r and ι and the sketch below will be used for that.

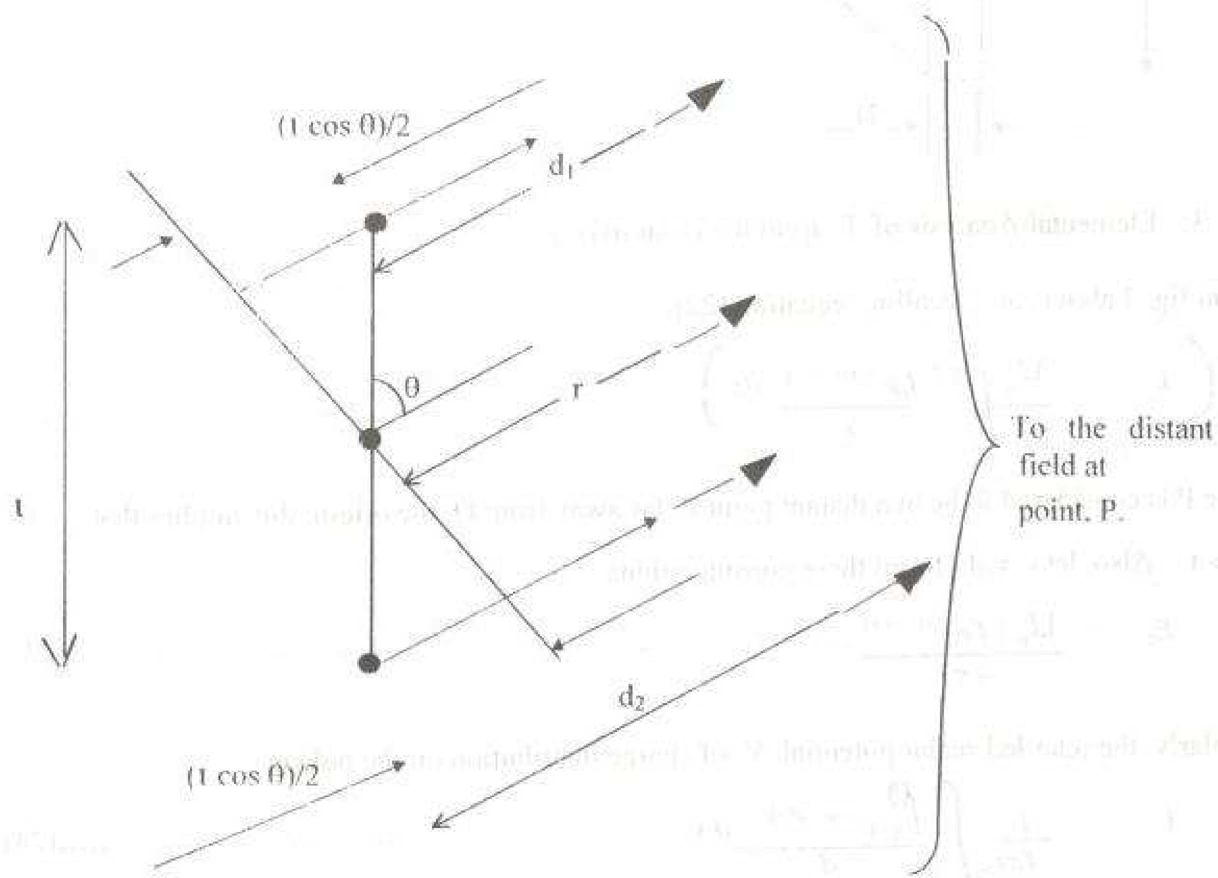

Fig. 4: Linear Orientation of ι for modifications of d in terms of r and ι

From fig. 4 above.

$$d_1 = r - \frac{\iota}{2}\cos\theta \quad \text{..........(27)}$$

$$d_2 = r + \frac{\iota}{2}\cos\theta \quad \text{.......... (28)}$$

Using these simplifications in equation (26), the following equation is obtained:

$$V = \frac{I_o}{4\pi\varepsilon_o j\omega}\left[\frac{e^{j\omega\left(t - \frac{r - \iota/2\cos\theta}{c}\right)}}{r - \frac{\iota}{2}\cos\theta} - \frac{e^{j\omega\left(t - \frac{r + \iota/2\cos\theta}{c}\right)}}{r + \frac{\iota}{2}\cos\theta}\right]$$

$$V = \frac{I_o e^{j\omega\left(t - \frac{r}{c}\right)}}{4\pi\varepsilon_o j\omega}\left[\frac{e^{(j\omega\iota\cos\theta)/2c}\left(r + \frac{\iota}{2}\cos\theta\right) - e^{(-j\omega\iota\cos\theta)/2c}\left(r - \frac{\iota}{2}\cos\theta\right)}{r^2}\right] \quad \text{.......... (29)}$$

Where the quantity $\frac{\iota^2\cos^2\theta}{4}$ in the denominator has been neglected as $r^2 - \frac{\iota^2\cos^2\theta}{4} \cong r^2$

From there,

$$V = \frac{I_o e^{j\omega\left(t - \frac{r}{c}\right)}}{4\pi\varepsilon_o j\omega r^2}\left[\left(\cos\frac{\omega\iota\cos\theta}{2c} + j\sin\frac{\omega\iota\cos\theta}{2c}\right)\left(r + \iota/2\cos\theta\right) - \left(\cos\frac{\omega\iota\cos\theta}{2c} - j\sin\frac{\omega\iota\cos\theta}{2c}\right)\left(r - \iota/2\cos\theta\right)\right] \quad \text{...... (30)}$$

$$\text{Now, } \cos\frac{\omega\iota\cos\theta}{2c} = \cos\frac{\cancel{2}\pi f\iota\cos\theta}{\cancel{2}c} = \cos\frac{\pi\iota\cos\theta}{(c/f)} = \cos\frac{\pi\iota\cos\theta}{(c/f)} = \cos\frac{\pi\iota\cos\theta}{\lambda} \quad \text{.... (31)}$$

Now, it is assumed that $\iota << \lambda$, hence $\cos\frac{\pi\iota\cos\theta}{\lambda} \cong \cos 0 = 1$ .... (32)

Also, θ varies from 0 to 90 degrees. Assuming θ is very small,

$$\sin\frac{\omega\iota\cos\theta}{2c} \cong \frac{\omega\iota\cos\theta}{2c}, \text{ in radians} \quad \text{.......... (33)}$$

Using the expressions in equation (32) and (33), V now becomes:

$$V = \frac{I_o e^{j\omega\left(t - \frac{r}{c}\right)}}{4\pi\varepsilon_o j\omega r^2}\left[\left(1 + j\frac{\omega\iota\cos\theta}{2c}\right)\left(r + \iota/2\cos\theta\right) - \left(1 - j\frac{\omega\iota\cos\theta}{2c}\right)\left(r - \iota/2\cos\theta\right)\right] \quad \text{.......... (34)}$$

After expansion and simplification, it is found that

$$V = \frac{I_o\,\iota\cos\theta\; e^{j\omega\left(t - \frac{r}{c}\right)}}{4\pi\varepsilon_o c}\left(\frac{1}{r} + \frac{c}{j\omega r^2}\right) \quad \text{.......... (35)}$$

The electric field at the distance r (OP) can then be obtained from the following equation:

$$E_p = \frac{dE_r}{dt} - \text{gradient of } V = j\omega E_r - \text{grad } V \quad \text{.......(36)}$$ [5]

the negative sign implying retardation. From equation (36), the components of the electric field in spherical co-ordinates r, θ and φ are as follows:

$$E_{p(r)} = -j\omega E_r - \frac{\partial v}{\partial r} \quad \text{.......(37)}$$

$$E_{p(\theta)} = -j\omega E_\theta - \frac{1}{r} \cdot \frac{\partial v}{\partial \theta} \quad \text{.......(38)}$$

$$E_{p(\phi)} = -j\omega E_\phi - \frac{1}{r \sin\phi} \cdot \frac{\partial v}{\partial \phi} \quad \text{.......(39)}$$

It is well-known that in spherical co-ordinates, $E_\phi = O$ [5], and as V is independent of φ, then

$$\partial v / \partial \phi = O \quad \text{.......(40)}$$

But recalling that $E_r = E_z \cos\theta$ and $E_\theta = - E_z \sin\theta$,

$$E_{p(r)} = -j\omega E_z \cos\theta - \frac{\partial v}{\partial r} \quad \text{.......(41)}$$

and

$$E_{p(\theta)} = -j\omega E_z \sin\theta - \frac{1}{r} \cdot \frac{\partial v}{\partial \theta} \quad \text{.......(42)}$$

Referring to equations (23) and (35) $E_{p(r)}$ and $E_{p(\theta)}$ can now be determined, from which the following equations result.

$$E_{p(r)} = \frac{-j\omega\mu_o\, t\, I\, e^{j\omega\frac{(t-r)}{c}} \cos\theta}{4\pi r} - \left[\left(\frac{-j\omega\, I_o\, t \cos\theta\, e^{j\omega\frac{(t-r)}{c}}}{4\pi\varepsilon_o c}\right)\left(\frac{1}{r} + \frac{C}{j\omega} \cdot \frac{1}{r^2}\right) + \left(\frac{I_o\, t\cos\theta \cdot e^{j\omega\frac{(t-r)}{c}}}{4\pi\varepsilon_o c}\right)\left(-\frac{1}{r^2} - \frac{2c}{j\omega} \cdot \frac{1}{r^3}\right)\right] \quad \text{.......(43)}$$

$$E_{p(r)} = \frac{I_o\, t\cos\theta \cdot e^{j\omega\frac{(t-r)}{c}}}{2\pi\varepsilon_o}\left(\frac{1}{cr^2} + \frac{1}{j\omega r^3}\right) \quad \text{.......(44)}$$

and $$E_{p(\theta)} = \frac{j\omega\mu_o t\, I_o e^{j\omega\frac{(t-r)}{c}} \sin\theta}{4\pi r} - \frac{1}{r}\left[-\frac{t\, I_o \sin\theta \cdot e^{j\omega\frac{(t-r)}{c}}}{4c}\left(\frac{1}{r} + \frac{c}{j\omega} \cdot \frac{1}{r^2}\right)\right]$$

$$E_{p(\theta)} = \frac{t I_o \sin\theta \cdot e^{j\omega\frac{(t-r)}{c}}}{4\pi\varepsilon_o}\left(\frac{j\omega}{c^2 r} + \frac{1}{cr^2} + \frac{1}{j\omega r^3}\right) \quad \text{.......(45)}$$

If very low frequencies are considered, then $I_o e^{j\omega\frac{(t-r)}{c}} = j\omega q_o e^{j\omega\frac{(t-r)}{c}}$

From which $E_{p(r)} = \dfrac{q_o e^{j\omega(t-\frac{r}{c})}\, \iota \cos\theta}{2\pi\varepsilon_o}\left(\dfrac{j\omega}{cr^2} + \dfrac{1}{r^3}\right)$ ....(46)

and $E_{p(\theta)} = \dfrac{q_o e^{j\omega(t-\frac{r}{c})}\, \iota \sin\theta}{4\pi\varepsilon_o}\left(\dfrac{-\omega^2}{c^2 r} + \dfrac{j\omega}{cr^2} + \dfrac{1}{r^3}\right)$ ....(47)

If $\omega \rightarrow 0$, then $E_{p(r)} = \dfrac{q_o\, \iota \cos\theta}{2\pi\varepsilon_o r^3}$ ....(48)

and $E_{p(\theta)} = \dfrac{q_o\, \iota \sin\theta}{4\pi\varepsilon_o r^3}$ ....(49)

where $E_{p(r)}$ = Electric field strength in volts/meter at the point P in the direction of r.

$E_{p(\theta)}$ = Electric field strength in volts/meter at the point P in the direction of θ.

q_o = Radiative charges from the DAS (in coulombs), into surrounding air space. (typical value: 6)[11].

ι = The length of each dissipator wire, about 0.3m.

θ = Angle in spherical co-ordinates that the electric field strength E (due to the activities of DAS) makes with the polar axis in the direction of P, say 60 degrees.

ε_o = Permittivity of free space having the value 8.855×10^{-12} Farad/Meter.

r = Distance (in meters) from the center of the dissipator O to a point, say P, where the electric field strength is to be determined, say 125 meters.

Substituting values in equation (48),

$$E_{p(r)} = \left(\frac{6 \times 0.3 \times 0.5}{2 \times 3.142 \times 8.855 \times 10^{-12}}\right)\left(\frac{1}{(125)^3}\right) = 8{,}281.19 \text{ volts/meter.}$$

$\therefore E_{p(r)} = 8{,}281.19$ *volts/meter* ....(50)

Similarly, from equation (49),

$$E_{p(\theta)} = \left(\frac{6 \times 0.3 \times 1.732}{4 \times 3.142 \times 8.855 \times 10^{-12}}\right)\left(\frac{1}{(125)^3}\right) = 14{,}583.0 \text{ volts/meter}$$

$\therefore E_{p(\theta)} \cong 15{,}000$ *volts/meter* ....(51)

9 Discussion

The knowledge of field theory has been very useful in determining the electric field strength E from the dissipating wire at a distant point P. It is the field E that provides the negative charges which neutralizes the positive charges in the atmosphere which would have otherwise caused lightning strike. From equations (48) and (49), it will be noticed that the field (which generates the negative space charges), is very strong near the origin but decreases as the distance r increases.

Since the invention of the DAS in 1990, the theory of its operation had not been well-developed. In the words of Lightning Eliminators & Consultants, (LEC) Inc., the inventors of the system, " the space charge shielding effect has been tested and proven by two independent atmospheric physicists and can be calculated using Poisson's equation" [2]. The Poisson's equation mentioned above is what is expressed in equation (8). The "calculation" mentioned in the quotation was never carried out rather, the effects of E were measured and recorded experimentally as shown in table 1 below [2].

Distance of Point, P from DAS, in meters	Electric Field Strength, E by measurement
125m	20,000 v/m
180m	14,000 v/m
200m	23,000 v/m

Table 1: Electric Field Strengths at various Points from the DAS [2]

10 Conclusion

As earlier mentioned, the inventors of the DAS never calculated the field strengths at various points from the device. They only measured and recorded its values at various points as illustrated in table 1 above. The calculations in this paper show that in the direction of q, at 125m from the DAS, the field strength E_1q_1 is about 15 Kv/m (eqn. (51)) while the measured value is 20 Kv/m. The figure, 15 Kv/m compares favourably with the measured 20 Kv/m when one considers certain variations like the angle q, atmospheric conditions, possible measurement errors, etc.

In this research paper, the author has delved extensively into electrostatic and electromagnetic field theories. Proven results have been used to establish the scientific and mathematical principles behind the operation of this lightning prevention device - the DAS. The theory behind the operation of the system is now clear. The work of the author explains and complements an earlier invention.

REFERENCES

1. **R. C. Weast,** *"Handbook of Chemistry & Physics,"* CRC Handbook series, 61st Edition, CRC Press, Inc., Boca Raton, Florida, (FL), United States of America (USA), (1990), pp. 212 - 214.
2. *"Dissipation Array Systems,"* Lightning Eliminators & Consultants, (LEC) Inc., (1997), p. 2.
3. *"Lightning Stroke Protection Criteria, Concepts and Configurations,"* Lightning Eliminators & Consultants (LEC) Inc., Report No. LEC-01-93, 6687 Arapalwe Road, Boulder, Colorado, (Co.), United States of America, (USA), (1993), p. 13.
4. **S. Ramo, J. R. Whinney & T. V. Duzer,** *"Fields & Waves In Communication Electronics,"* John Wiley & Sons Inc., New York (NY), United States of America (USA), (1965), pp. 254 - 256.
5. **H. H. Skilling,** *"Fundamentals of Electric Waves,"* John Wiley & Sons, Inc., New York (NY), United States of America (USA), (1948), Table II, pp. 93-167.